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Estimation of the Applicability for the Filler Produced by Recycling of Concrete and Reinforced Concrete Used in Heavy Concrete

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Abstract

The estimation of the secondary filler applicability showed that secondary rubble and sand on all indicators satisfy the standard requirements (except the content of dust particles and clay particles) and can be used as filler for construction works. The content of particles sized less than 0.16 mm is 8%, which exceeds the requirements. However, the chemical analysis shows that these particles consist of hydrated and non-hydrated cement particles. The amount of non-hydrated cement, based on cement consumption is about 10%. Consequently, in the course of cement materials production using the secondary rubble and sand you can either reduce the cement consumption or increase the strength of products while maintaining the cement consumption. In turn, the hydrated cement particles can act as additives - the substrates for crystallization. Thus, the screening is a multimineral active additive to cement-based materials.

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Keywords: Concrete Waste; Secondary Filler; Multimineral Active Additive; Recycling.

1. Introduction

Development of the construction industry necessitates the creation of efficient high-quality materials, the use of which is economically feasible and can reduce energy costs and consumption of raw materials [1, 2]. This tendency extends to the maximum use of Portland cement potential [3, 4] and applying the waste of concrete and reinforced concrete [6-8], as reinforced concrete structures and concrete products are the foundation of modern construction.

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In a number of Russian cities the demolition of older armored concrete constructions is carried out. The plants producing armed concrete products also accumulate a large number of sub-standard products. In addition, the formless method in reinforced concrete producing became widespread, as a result of a large amount of waste comes during cutting. This is the raw material to produce recycled rubble [2, 9-11].

2. Actuality

The problem of construction waste recycling is acute throughout the civilized world. Ac-cording to the European Association for the demolition of buildings, established in 1976, every year on the planet about 2.5 billion tons of construction waste are generated, including 200 million tons in Europe.

A significant number of residential and industrial buildings in Russia was built in the 60s of the last century. Reinforced concrete, which is the basic building material of these objects have al-ready exhausted their resources [2, 5, 6-9]. Today, the issues of recycling and utilization of mate-rials from the residential and industrial constructions dismantling are very relevant.

There are two ways of utilization of concrete and reinforced concrete waste:

- burial at specially allocated polygons and dumps;
- complete processing using a special crushing machinery.

Until recently, the only way for construction waste utilization was first variant, but this method of utilization creates great ecological problems. Thus, the recycling of construction waste and the creation of recycling system becomes highly profitable perspective production that solves an important ecological and economic problem. Secondary rubble made from concrete is much cheaper than natural, since the energy consumption for its manufacture is less more than 8 times, and the cost of concrete with secondary rubble is reduced by 25% [12, 13].

It was justified the use of crushing screenings (fractions 0-10 mm) in construction materials production [14, 15]. Investigation the screenings by X-ray and by integrated thermal analysis showed that it consists of amorphous and crystalline phases in the ratio of (55-60%) to (40-45%), respectively [16]. The crystalline phase includes the following minerals: quartz, feldspar, calcite, dolomite, Portland, ettringite, limestone, calcium silicate and unhydrated cement minerals. Special screening treatment has shown that screening is capable of self-hardening, there may be achieved a considerable strength of the stone.

Note quite slow development of the cement hydration process at later stages [17 - 20]. In the samples that stored over 20 years at sea, 16-17 years under normal conditions, and 18 years in the ground, 30 - 40% of Portland cement did not react with water. Non-hydrated cement grains are composed of crystals alite, belite and compound of calcium, aluminum and ferrum oxides. Hydra-tion products in the form of gelatinous masses are accumulated around the parts of the grains. After compaction and solidification they enhance the strength of cement. Hydration products have a colloidal size in the hardened cement paste age of 12 (except for $Ca(OH)_2$).

Study of Portland cement samples hardened for 40 years showed that they contains unhydrated clinker grains with size of 10 - 100 microns [20]. According to the results of determination the loss of mass, the degree of hydration was in samples stored under different conditions, %: in air-humid conditions and in the water – 75 - 80, in air dry conditions – 25 - 30. According to the quantitative X-ray analysis the degree of C3S hydration was, %: when stored in air-dry conditions – 66.50; in water – 97.96 and in air-humid conditions – 97.7.

3. Problem Statement

The feature of filler, produced by recycling, is that it is a heterogeneous mixture of fragments-conglomerates of hardened cement paste, large and small fillers. Screenings contains a significant portion of the hardened cement paste, which, depending on the operating conditions of a concrete construction (demolished building) could corrode. The purpose of this study was to evaluate the suitability of filler, produced by recycling, for use in the cement materials (cement-sand mortar, concrete, etc.).

4. Results of Experimental Studies

We used the following materials: Portland cement, sand and rubble, natural and produced from concrete waste and reinforced concrete waste. Portland cement produced by LLC "Iskitimcement" (Novosibirsk Region), grade PTs 400 D-20 was used as a binder. The mineral composition of the cement, % of weight: C3S – 50-55, C2S – 18-22, C3A – 7-11, C4AF – 12-15 and a specific surface area of 320 m2/kg. The chemical composition, % of weight: SiO2 – 20.7; Al2O3 – 6.9; Fe2O3 – 4.6; CaO – 65.4; MgO – 1.3; SO3 – 0.4; loss on ignition – 0.5.

The diabase rubble and the rubble produced by recycling of concrete and reinforced concrete were used as a coarse filler. The diabase rubble had grain size 5 - 20mm and Mark on crushability – 1200, Mark on frost resistance – F300. Bulk density of rubble was 1360 kg / m3, the true density – 2750 kg / m3. The content of impurities, needle-like particles, and lamellar particles in the rubble satisfied the requirements of GOST 8267.

The chemical composition of diabase, % of weight: SiO2 – 47.36; Al2O3 – 16.68; Na2O – 3.08; FeO – 8.96; Fe2O3 – 7.75; CaO – 3.85; MgO – 7.75; K2O – 0.31; TiO2 – 0.18.

Filler produced of recycled concrete waste and reinforced concrete waste was a mixture of sand and rubble. Therefore, the particle size analysis was carried out for the mixture. This mixture was sifted then to give a crushed sand with a particle size less than 5 mm (the secondary sand) and rubble (the secondary rubble). Properties of recycled rubble and the requirements of GOST 8267 are given in Table. 1.

Table 1. Properties of recycled rubble and GOST 8267 requirements

№	Parameter	Test results	GOST 8267 requirements
1	Content of dust and clay particles, (%)	8	No more than 1
2	Content of clay in globs	No	No more than 0.25
3	Content of lamellar and needle-like particles, (%):		
	fraction 5-10 mm	10.00	Up to 10 incl.
	fraction 10-20 mm	15.20	Over 15 to 25 incl.
	fraction 20-40 mm	12.90	Over 10 to 15 incl.
	fraction 5-40 mm	13.50	Over 10 to 15 incl.
4	Mark on the crushability for fractions:		
	fraction 5-10 mm	5.40	Up to 11 incl.
	fraction 10-20 mm	5.73	
	fraction 20-40 mm	6.91	
	fraction 5-40 mm	6.05	
5	Mark on abrasion, weight loss, (%)	21.62	Up to 25 incl.
6	Content of soft rock grains, (%)	3.8	Up to 5
7	Bulk density of the fractions:		
	fraction 5-10 mm	1200.0	
	fraction 10-20 mm	1150.5	
	fraction 20-40 mm	1095.0	
	fraction 5-40 mm	1280.0	
8	True density	2450.0	
9	Mark on frost resistance / weight loss, (%)	F150 / 4.1	No more than 5
10	Chemical resistance to alkali of cement	Resistant	Resistant

The data of particles size analysis of sand and rubble mixture, produced by recycling concrete waste , are shown in Table. 2.

Table 2. Data of particles size analysis of sand and rubble mixture, produced by recycling concrete waste

Residues on sieves	Sieve openings size, (mm)								Passed through sieve № 0.16
	40-20	20-10	10-5	2.5	1.25	0.63	0.315	0.16	
Partial residues, (g)	1685	3485	1845	315	155	230	145	75	80
Partial residues, (%)	16.85	34.85	18.45	31.5	15.5	23.0	14.5	7.5	8.0
Full residues, %				31.5	47.0	70.0	84.5	92.0	–

Note. For sieve with size less than 5 mm weighing weight was 2,985 kg or 29.85%. The size module for fraction less than 5 mm is 3.25.

According to the chemical analysis the mineralogical composition of the secondary rubble was calculated (Table. 3).

Table 3. Mineralogical composition of secondary rubble

№	Mineral name (the product of cement hydration)	Chemical formula	Content, (%)
1	Quartz	SiO_2	50.6
2	Calcite	$CaCO_3$	30.0
3	Vaterite	μ-$CaCO_3$	1.5
4	Ettringite	$3CaO{\cdot}Al_2O_3{\cdot}3CaSO_4{\cdot}31H_2O$	1.0
5	Unhydrated Portland	C_3S. C_2S. C_3A. C_4AF	4.8
6	Calcium silicate	C-S-H	5.6
7	Dicalcium aluminate 8-water	C_2AH_8	0.5
8	Tricalcium aluminate hexahydrate	C_3AH_6	2.6
9	Tetracalcium alumina ferrite hexagon	C_4AFH_6	2.8
10	Other components	–	1.5

The data in Table 3 show the presence of unhydrated Portland cement in the secondary rubble, and this agree with the results of J.M. Butt, V.V. Babkova, T.Y. Lubimova. It allows effectively use the secondary rubble in the production of building materials based on cement, as it enhances the strength of cement materials without increasing the consumption of cement, or even reduce it.

The quartz sand of "Kamnerechensky Kamenni Karier", which is one of the structural divisions of JSC "NerudZapsib", and the sand produced by concrete waste and reinforced concrete wast recycling (the secondary sand) were used. The mineral composition of natural quartz sand, % of weight: quartz 80 - 90, feldspar 10 - 20. The actual value of specific effective activity of natural radionuclides is 134 Bq / kg, i.e. the sand corresponds to the first class and is suitable for any kind of residential and public construction. True density of sand grains was 2650 kg/m3. The sand bulk density was 1420 kg/m3. The particles size modulus was 1.91. The content of silt, clay and dust impurities was 0.5 %, clay lumps were absent. Properties of secondary sand and GOST 8736 requirements are shown in Table. 4.

The particles of hydrated cement, contained in dust particles in the secondary sand-rubble mixture, form about 11% of the binder. Consequently, it is necessary to carry out the analysis of particle size for these particles.

The average size by volume was determined by laser granulometry. It was 33.9 microns. The specific surface of the powder was 287 m2 / kg that is very close to the cement surface area. The particle density was 3115 kg / m3.

Table 4. Properties of secondary sand and GOST 8736 requirements

№	Parameter	GOST 8267 requirements	Test results
1	Grain composition:		
	Group of sand	Increased size	Increased size
	Full residues on sieve № 063, (%)	More than 65 to 70	70
	Particle size modulus	More than 3 to 3.5	3.25
2	Content of grain with size less than 0.16 mm, (%)	No more than 5	8
3	Content of dust and clay particles, (%)	No more than 3	2.8
4	Content of clay in globs, (%)	No more than 0.35	0
5	Mark by strength for sand, produced from crushing screenings /	1000 /	1000 /
	Compressive strength in a water-saturated state, (MPa)	at least 100	124
6	Chemical resistance to alkali of cement	Resistant	Resistant
7	Bulk density	–	1270
8	True density	–	2450

The optimum amount of hydrated cement particles can be determined based on the formula [21, 22]

$$m = 8.3\,\frac{DA \cdot \rho A}{Dc \cdot \rho c} \qquad (1)$$

where m – the percent of the introduced additive by the cement weight; D_A – the diameter of the additive particles, microns; ρ_A – the additives density, g / cm^3; D_C – the diameter of cement particles, microns; ρ_C – the cement density, g / cm^3.

Thus, the optimal amount of hydrated cement, calculated according to a formula is 10.98 % by weight. This value is close to the amount of the hydrated cement particles in the secondary rubble. The difference may be due to the difference in density and particle size.

Of course, these calculated results are approximate, since the actual shape of the cement particles and additives (hydrated cement) is not spherical, and also cement and additives are spread on the particle size [21, 22]. Also the distribution of additive particles among cement particles may be irregular. However, the qualitative and quantitative evaluation of the optimum amount of additives is very close to the real.

5. Conclusion

Estimation of the secondary filler applicability showed that the secondary rubble and sand on all indicators except the content of dust and clay particles, satisfy the requirements of GOST 8267 and GOST 8736 and can be used as a filler for construction works. The content of particles with the size less than 0.16 mm exceeds the requirements of GOST, and is equal to 8%. However, the chemical analysis showed that these particles consist of hydrated and unhydrated cement particles. The amount of unhydrated cement, based on cement consumption is about 10%. Consequently, in the production of cement materials using the secondary rubble and sand you can either reduce the cement consumption up to 10% or increase the strength of products while maintaining the cement consumption. In turn, the hydrated cement particles can act as an additives – the substrates for crystallization. Thus, the screening is a multimineral active additive to cement-based materials.

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